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Seasonal Mean Variability of Coral-based Sea Surface Salinity from Simeulue, Mentawai, Bunaken, and Bali

Variabilitas Rata-rata Musiman Salinitas Permukaan Laut berbasis Koral dari Simeulue, Mentawai, Bunaken, dan Bali

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Abstract

Sea surface salinity is an important parameter in a climate study. Coral $\delta^{18}O$ records $\delta^{18}O$ seawater and sea surface temperature (SST). While, coral Sr/Ca records SST only commonly used in a paleoclimate study to reconstruct SST. Thus, paired coral $\delta^{18}O$ and Sr/Ca can be used to reconstruct $\delta^{18}O$ seawater. $\delta^{18}O$ seawater and SSS is linearly correlated, thus reconstructed $\delta^{18}O$ seawater further is used to reconstruct sea surface salinity (SSS). Instead of using coral Sr/Ca as SST recorder, paired model (grid) or measured SST data is used to reconstruct SSS. In this study, paired coral $\delta^{18}O$ and grid SST data are presented to reconstruct SSS from several different locations across Indonesian sea *i.e* Simeulue, Mentawai, Bunaken, and Bali. Coral-based SSS reconstructions from those locations are then compared to the grid SSS in the seasonal mean scale. The result shows that annual mean variation of salinity for period of 1958-2008 in Mentawai and Simeulue is 33.25 psu and 33.26 psu respectively, while in Bunaken and Bali is 34.03 psu and 33.47 psu respectively. Correlation coefficient between coral salinity and salinity from model data in the seasonal/monthly mean scale is high *i.e* R = 0.62 - 0.83. Based on the monthly mean data, corals in the studied area strongly record SSS variation in the monthly or seasonal mean scale. In Mentawai and Simeulue waters, SSS variation is influenced strongly by monsoon. While, in addition to the monsoon, ocean advection also affects seasonal variability of SSS in the Bunaken and Bali waters.

Keywords: salinity, coral, $\delta^{18}O$, SST, Simeulue, Mentawai, Bunaken, Bali

Abstrak

Salinitas permukaan laut (SSS) merupakan salah satu parameter penting dalam studi iklim. Kandungan $\delta^{18}O$ dalam karang merekam $\delta^{18}O$ air laut dan suhu permukaan laut (SPL). Sementara kandungan Sr/Ca dalam karang hanya merekam SPL dan telah banyak digunakan untuk rekonstruksi SPL dalam studi iklim masa lampau, sehingga pasangan $\delta^{18}O$ dan Sr/Ca dalam karang sering digunakan untuk merekonstruksi $\delta^{18}O$ air laut. Hubungan antara $\delta^{18}O$ air laut dan SSS adalah linier, maka hasil rekonstruksi $\delta^{18}O$ air laut selanjutnya dapat digunakan untuk menghitung SSS. Data model (grid) maupun pengukuran SPL dapat digunakan untuk merekonstruksi SSS jika hanya diketahui kandungan $\delta^{18}O$ karang saja, yaitu rekonstruksi SSS dapat menggunakan pasangan data grid SPL dan $\delta^{18}O$ dalam karang. Dalam penelitian ini dilakukan rekonstruksi SSS dari kandungan $\delta^{18}O$ karang dan data grid SPL dari beberapa lokasi di perairan Indonesia, yaitu perairan Simeulue, Mentawai, Bunaken, dan Bali. SSS hasil rekonstruksi kemudian dibandingkan dengan SSS dari data model dalam resolusi musiman (rata-rata bulanan). Hasilnya menunjukkan rata-rata tahunan salinitas selama periode 1958-2008 di lokasi Mentawai dan Simeulue masing-masing adalah 33.25 psu dan 33.26 psu, sementara di Bunaken dan Bali adalah 34.03 psu dan 33.47 psu. Koefisien korelasi antara hasil rekonstruksi

SSS dan SSS dari data model pada skala musiman/rata-rata bulan adalah sekitar R=0.62 - 0.83. Rekaman karang dari Mentawai dan Simeulue menunjukkan bahwa variasi SSS di daerah tersebut lebih dipengaruhi oleh musim. Sementara itu rekaman karang dari wilayah Bunaken dan Bali menunjukkan bahwa sirkulasi laut berperan juga dalam memengaruhi variasi SSS di wilayah tersebut selain juga variasi musim.

Kata kunci: *salinitas, koral, δ^{18}O , SST,* Simeulue, Mentawai, Bunaken, Bali

Introduction

Sea surface salinity (SSS) is an important parameter for climate study. To understand more climate changes of the region, long time series data of climate parameters are required. Climate archives such as coral, sediment, and tree rings are able to provide long time series data of climate parameters from present time to hundreds even thousands years ago. Geochemical proxy content in coral skeleton is able to record climate parameters in monthly resolution and continuously from present time till hundreds years ago. Sr/Ca and δ^{18}O are most commonly proxies used in a paleoclimate study. Coral Sr/Ca is known as a temperature proxy (Cahyarini *et al.*, 2009; De Villier *et al.*, 1994), while coral δ^{18}O is influenced by δ^{18}O seawater and SST (Gagan *et al.*, 1994; Charles *et al.*, 2003). Thus paired coral Sr/Ca and δ^{18}O is used to reconstruct δ^{18}O seawater (Cahyarini *et al.,* 2008; Ren *et al*., 2002). δ^{18}O seawater and SSS are linearly correlated (Schmidt, 1999), then reconstructed δ^{18}O seawater can further be used to reconstruct SSS (*e.g*. Hernawan, 2011). In this study, paired coral δ^{18}O and SST from the data model (further mentioned as grid SST) is used to reconstruct δ^{18}O seawater and further to reconstruct SSS. Using grid SST instead of coral Sr/Ca is expected to reduce the proxy error in the SSS reconstruction (Cahyarini *et al*., 2008).

Several studies on coral δ^{18}O have been done in Indonesia. Charles *et al.* (2003) mentioned that coral δ^{18}O from Bunaken and Bali records the influence of ENSO to the rainfall variability in Bunaken and Bali. Abram *et al.* (2008) indicate that coral δ^{18}O from Mentawai Islands records the gradient of SST anomaly between the western and eastern Indian Ocean. Mentawai coral is also as good recorder of the Dipole Mode Index (DMI) (Abram *et al*., 2008). Study on coral based-salinity reconstruction in Indonesia is done by Cahyarini *et al.* (2008). She used paired of coral Sr/Ca and δ^{18}O from Timor to reconstruct δ^{18}O seawater which further to reconstruct SSS. Their results show that salinity variation is well recorded in the core top of Timor coral. Hernawan *et al*. (2012) used paired coral δ^{18}O and grid SST to reconstruct past SSS from the eastern Indonesia (*i.e*. Bunaken and Bali). They mentioned that Bunaken coral recorded clearly annual mean and monthly variation of the local waters surface salinity. Meanwhile, Padang Bai (Bali) coral shows more clearly annual mean SSS variation than its monthly variation. In this study, the new monthly mean variation of coral δ^{18}O records from Simeulue will be presented, and also the seasonal mean variability of reconstructed SSS from Simeulue, Mentawai, Bunaken, and Bali are presented. The variability of seasonal mean coral SSS from different location then reanalyzed and compared.

Material and Methods

Porites coral was collected in 2007 from Labuan Bajo Simeulue waters. δ^{18}O content in Simeulue coral was analyzed using a Thermo Finnigan MAT DELTA Plus Gasbench II at Vrije University Amsterdam. The powdered coral samples were reacted with H_3PO_4 and the resulting CO_2 gas was analyzed in the mass spectrometer. The standard used for δ^{18}O is NBS-19. The standard deviation of multiple sample of the international reference standard NBS-19 is ±0.06‰ for δ^{18}O. All samples are reported in ‰ relative to Vienna Pee Dee Belemnite (VPDB) by assigning a δ^{18}O value of - 2.2 ‰ to NBS-19.

In this study, the available data of coral δ^{18}O are also used, *i.e.* δ^{18}O content in *Porites* coral from Bunaken and Bali (from Charles *et al*., 2003 records) and coral δ^{18}O from Mentawai (from Abram *et al*., 2008 records). Figure 1 shows the location of coral samples used in this study. Coral δ^{18}O records from

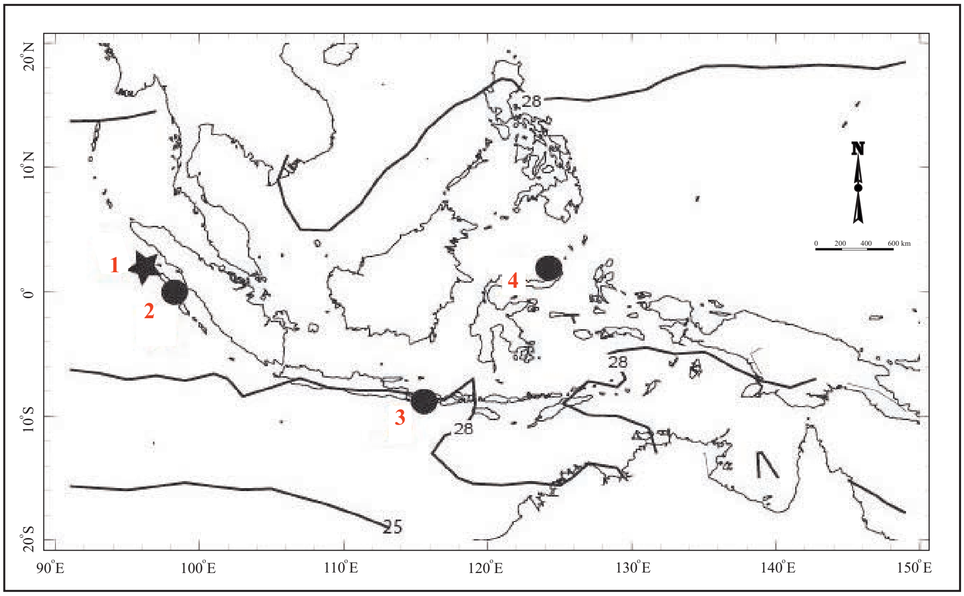

Figure 1. Indonesia map with monthly mean variation of SST (contours) and the location of coral samples *i.e.* 1. Simeulue, 2. Mentawai, 3. Bali, and 4. Bunaken.

Bunaken extent from 1860-1960 and Bali coral $\delta^{18}O$ records are from 1854-1990 (Charles *et al*., 2003). The Mentawai coral $\delta^{18}O$ extent from 1858-1997 (Abram *et al*., 2008). Based on the chronology development using anchor point method (see detailed method in Cahyarini *et al*., 2009), Simeulue coral $\delta^{18}O$ extent from 1993 to 2007.

These coral $\delta^{18}O$ records were reanalyzed using statistical timeseries analysis approach. KNMI explorer (Olderborg and Burgers, 2005), and excels sheet software were used to process statistical time series data. SSS variation was reconstructed using coral $\delta^{18}O$ and grid SST. SST local coordinate of the coral sample was converted into $\delta^{18}O$ unit to get the $\delta^{18}O$ variation relative to the SST. It is known that the changes of coral $\delta^{18}O$ relative to SST is -0.22 ‰/°C (Weber and Woodhead, 1972), thus the conversion unit of SST to coral $\delta^{18}O$ is by multiplying SST value with a factor of -0.22. Coral $\delta^{18}O$ was then subtracted by the coral $\delta^{18}O$ changes relative to SST to get the $\delta^{18}O$ seawater variation. If the $\delta^{18}O$ seawater changes relative to SSS in Indonesia water is about 0.44‰/psu (Cahyarini *et al*., 2008), thus reconstructed SSS (further mentioned as coral SSS) can be calculated by dividing $\delta^{18}O$ seawater with factor of 0.44. In this study, the changes of SSS were reconstructed not the absolute value of SSS. The more detailed reconstruction SSS method using paired grid SST and coral $\delta^{18}O$ see Hernawan *et al*., (2012), Hernawan (2011), and Cahyarini (2010). In this study, SST from ERSST (Extended Reconstructed Sea Surface Temperature) (Smith and Reynolds, 2004) dataset was used (mentioned as grid SST). Sea surface salinity (SSS) from the Simple Ocean Data Assimilation (SODA) version v2p1p6 (Carton and Giese, 2007) was used for coral SSS calibration.

Indonesian Throughflow (ITF) surface transport time series data (available from period of 1995 to 2004) through the outflow Indonesian throughflow, which measured at Ombai strait (*i.e*. Hautala *et al*., 2001) was also used in this study. ITF data was obtained from Hautala *et al.* (2001) dataset. These data will be compared with coral SSS, to analyze the variability of coral SSS relative to the ITF surface transport at the studied area.

Results and Discussion

Monthly mean variation of sea surface salinity from the SODA model dataset (further mention as SSS_{soda}), shows that the maximum and minimum SSS from these four locations *i.e*. Simeulue, Mentawai, Bali and Bunaken (Figure 1) are different. The maximum/minimum SSS from eastern Indonesia region *i.e.* Bunaken and Bali occurs in September/April for Bali and August/January for Bunaken, while the maximum/minimum SSS for western Indonesia region *i.e.* Simeulue and Mentawai occurs in August/January for Mentawai, and July/January for Simeulue (Figure 2). Monthly mean data were taken by averaging SODA SSS data for starting month in the similar period with the coral δ^{18}O.

Averaged SODA SSS for the annual mean variation is 33.25±0.12 psu in the Mentawai waters, and 33.26±0.11 psu in Simeulue waters. For Bali waters is 33.47 ±0.63 psu and 34.03±0.07psu for Bunaken (Table 1). The SSS_{soda} model shows that the average SSS in annual mean scale in the western Indonesia (Mentawai and Simeulue) is about 1 psu fresher compare to the eastern Indonesia (average SSS of Bunaken and Bali).

The changes of SSS were reconstructed using paired coral δ^{18}O and SST (further mentioned as coral SSS) to get the longer variation on salinity. The changes of δ^{18}O content in coral are influenced by δ^{18}O seawater and sea surface temperature. Thus, if SST and δ^{18}O coral are known then δ^{18}O seawater changes with respect to δ^{18}O seawater can be reconstructed. Coral δ^{18}O changes relative to δ^{18}O seawater was obtained by subtracting the changes of coral δ^{18}O with coral δ^{18}O changes relative to SST. δ^{18}O seawater is influenced by SSS (see Schmidt 1999), the relative changes of δ^{18}O seawater to SSS in Indonesia is about 0.44 permil/psu (based on GISS dataset by Cahyarini *et al*., 2008). To get the SSS changes, coral δ^{18}O changes relative to δ^{18}O seawater were divided by 0.44 permil/psu. In this

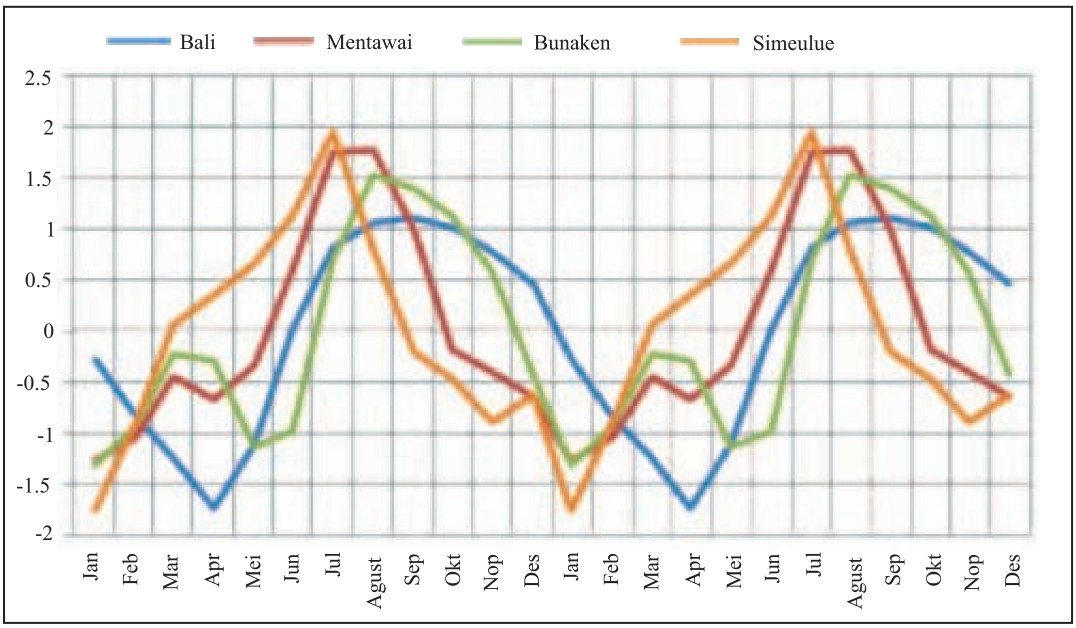

Figure 2. Monthly mean variation of SODA SSS data at the coral sites: *i.e.* Bali, Mentawai, Bunaken, Simeulue. Data were obtained from SODA (Carton and Giese, 2007) for the coordinate of the coral sites. SSS data are standardized ones.

Tabel 1. Descriptive Statistics of Annual Mean SSS (Data from SODA-Carton and Giese, 2007)

	Bali	**Bunaken**	**Mentawai**	**Simeulue**
Mean	33.47	34.03	33.25	33.26
Standard Deviation	0.63	0.07	0.12	0.11
Minimum	32.38	33.94	33.09	33.06
Maximum	34.16	34.14	33.46	33.47

study, the monthly mean variation of coral SSS was then compared with SSS_{soda}. Monthly mean variation of coral SSS leads to SSS_{soda} by about 6 - 9 months. The SODA SST increases lead to SSS, this probably influences the reconstruction of SSS using the SODA SST and coral $\delta^{18}O$.

Based on monthly mean data, corals in the studied area strongly record SSS variation in the monthly or seasonal mean scale. The seasonal mean calibration of coral SSS and SSS_{soda} result in r value = 0.799 for Mentawai coral and r = 0.778 for Simeulue coral. While for Bali and Bunaken coral, r values are 0.624 and 0.826 respectively. Figure 3 shows a scatter plot between coral SSS and SODA SSS.

The variation of surface SSS in Indonesian sea is influenced by the monsoon system and ocean advection. During the northwest monsoon, the fresh water from South China Sea flows into Indonesian sea, oppositely during the southeast monsoon, it flows back into the South China Sea (Gordon *et al*., 2003). In Bunaken, SSS starts increasing in June and decreasing in November. During the northwest monsoon the fresh South China Sea water flows further to the east (Gordon *et al*., 2003), however the ocean advection brings more saline water from the bottom to the surface. In the eastern Indonesian region such as Bunaken and Bali, monsoon and ocean circulation strongly influence the SSS variation. Figure 4 shows the comparison of monthly mean reconstructed SSS and SODA salinity.

Besides, in these regions sea surface temperature (SST) co-varies inphase with SSS, higher SST (high

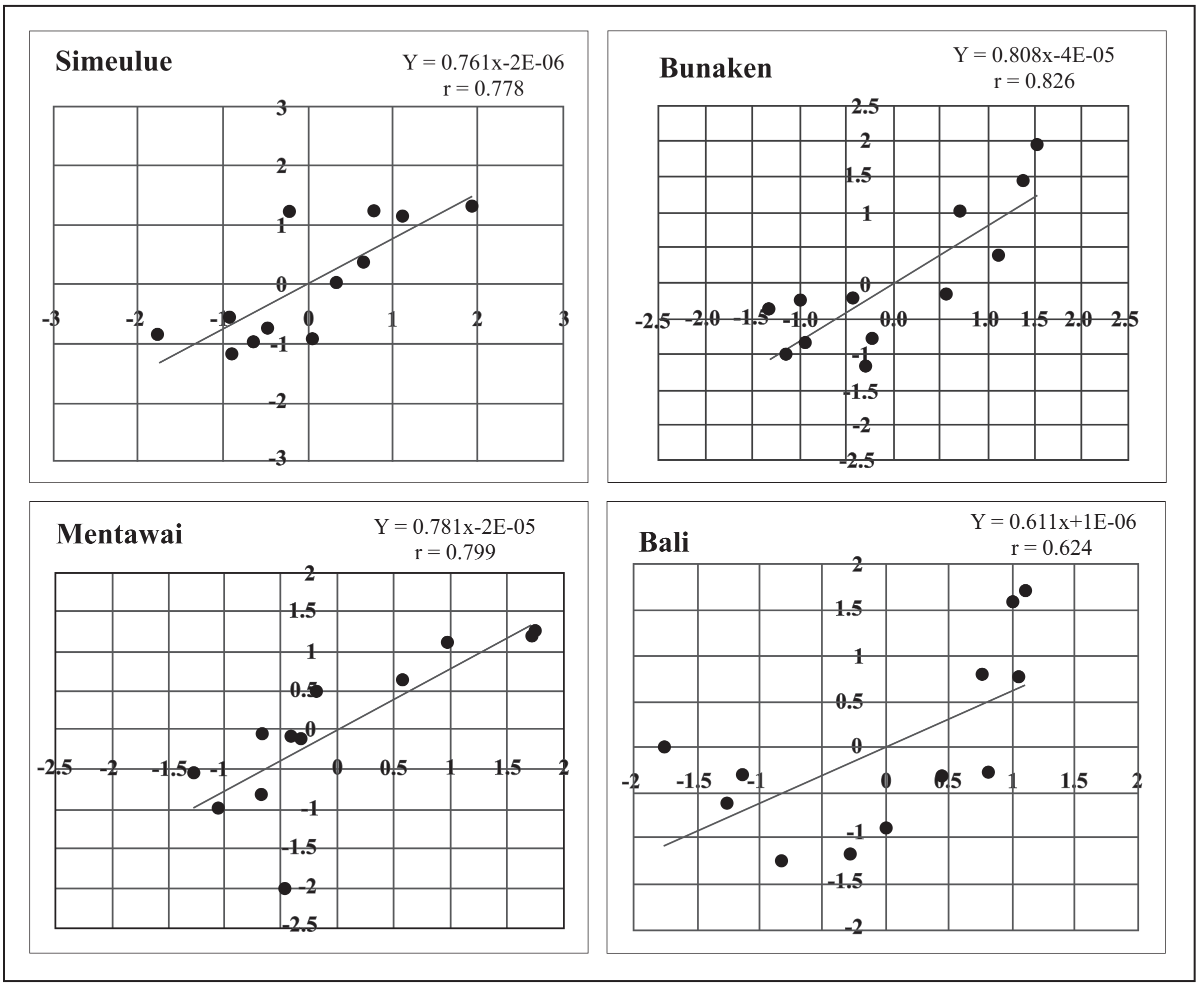

Figure 3. Scatter plot diagram of coral SSS and SODA SSS for monthly mean scale.

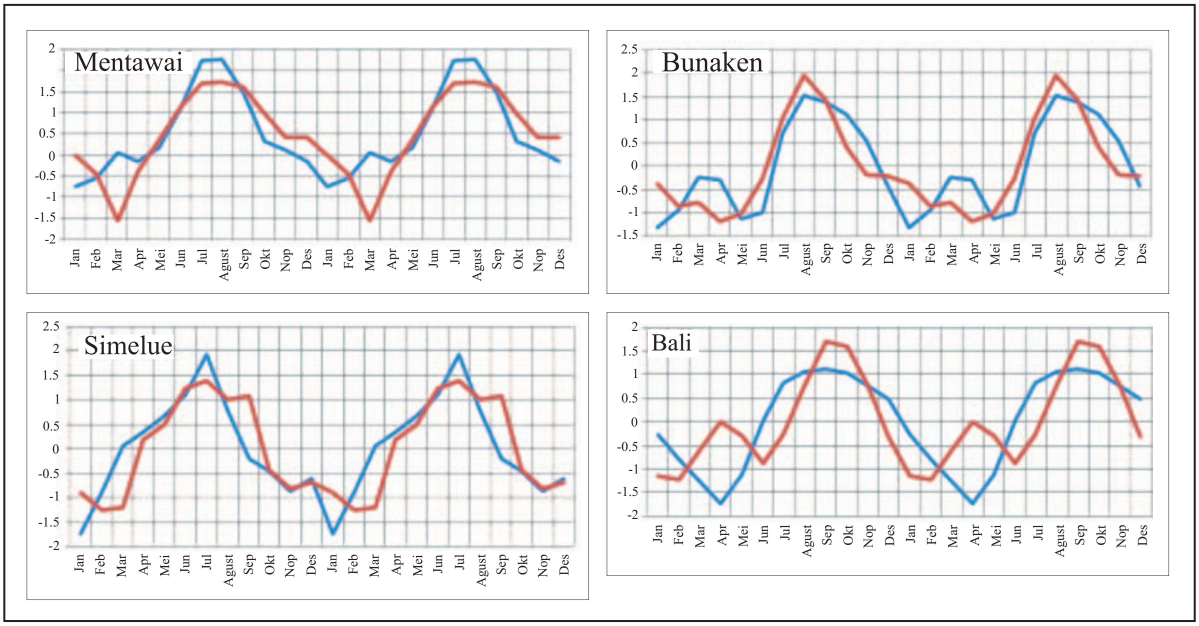

Figure 4. Comparison of monthly-average SSS records via corals (red) and SODA dataset (blue). Our coral-based SSS records lead SODA SSS by about 6-9 months. The monthly average values at each site were calculated for the period of: Mentawai (1858-1997), Simeulue (1993-2007), Bunaken (1860-1990), and Bali (1854-1990). SODA SSS (blue), Coral SSS (red). SSS data are a standardized ones.

evaporation) leads to the high SSS. In the western Indonesia (*e.g*. Simeulue and Mentawai) SSS variation is strongly influenced by the monsoon, where maximum SSS is found during SE monsoon when the precipitation is low.

Coral SSS is also compared to the Indonesian throughflow surface transport measured at Ombai strait exit passage (Hautala *et al*., 2001). The corals are located along the ITF pathway (Bali, Bunaken) and inner western Indonesian seas (Mentawai, Simeulue). The Bali and Bunaken corals show their sensitivity to ITF transport, while the western Sumatra (Mentawai, Simeulue) corals show less such sensitivity. Increasing ITF transport towards Indian Ocean coincides with decreasing SSS in the Mentawai and Simeulue, while in Bali and Bunaken showing increasing surface transport, it coincides with increasing SSS in this region (Figure 5).

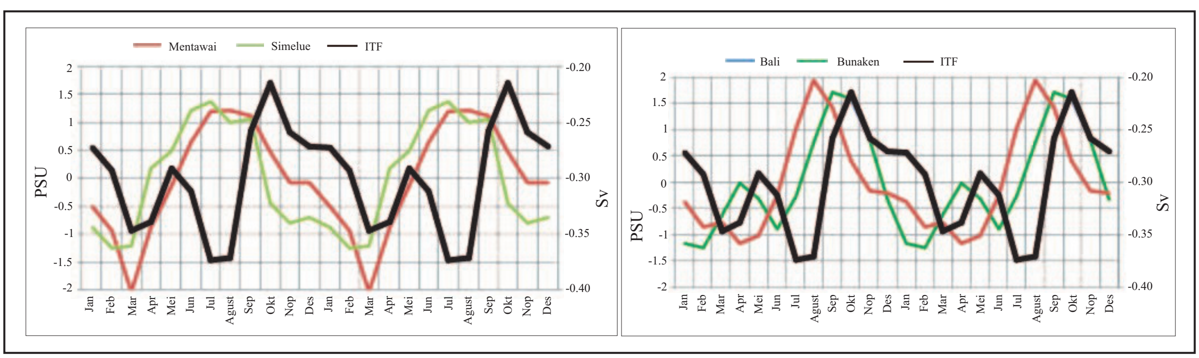

Figure 5. Monthly mean SSS variations reconstructed from corals are compared to the ITF surface transport (in Sv). The negative ITF transport denotes a southward transport towards the Indian Ocean. Corals located along the ITF pathway and inner western Indonesian seas show their sensitivity to ITF transport, while the western Sumatra corals do not show such sensitivity.

Conclusions

In this study, seasonal variation of SSS was reconstructed based on paired coral $\delta^{18}O$ and grid SST. Seasonal mean variation of coral SSS from different locations in Indonesia *i.e*. Bali, Bunaken, Mentawai, and Simeulue is presented. Coral SSS from those four locations are compared. The result shows that corals from the studied area record salinity variation in the seasonal scale, this is shown by a high correlation coefficient between coral salinity and salinity from model data in the seasonal *i.e.* r=0.62 - 0.83. The seasonal mean variations of coral SSS from the western (Simeulue, Mentawai) and eastern (Bali, Bunaken) Indonesia both are influenced by the monsoonal system. However, in the eastern Indonesia, the surface transport also influence seasonal mean SSS variation besides the monsoon. ITF surface transport shows in phase with coral SSS in Bali and Bunaken, and it shows out of phase with coral SSS in Simeulue and Mentawai. Increasing ITF transport toward Indian oceans coincides with decreasing SSS in the Mentawai and Simeulue, while in Bali and Bunaken showing increasing surface transport it coincides with increasing SSS in this region

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